EUROPEAN UNION

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"Investing in Sustainable Development"

Prompt gamma rays from the spontaneous fission of ^{252}Cf and their angular distributions

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Outline

- Introduction
- Experimental setup
- Data treatment
- Preliminary results
- Discussion
- Summary & outlook

Introduction

- For many years: precise measurement of prompt fission γ-ray spectra (PFGS)

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  - $< M_\gamma >$, $< \varepsilon_\gamma >$, and $< E_{\gamma,tot} >$

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- Studies of the dependence of A, Z, and E_x

Introduction

PFGS characteristics as function of A, Z and E_x

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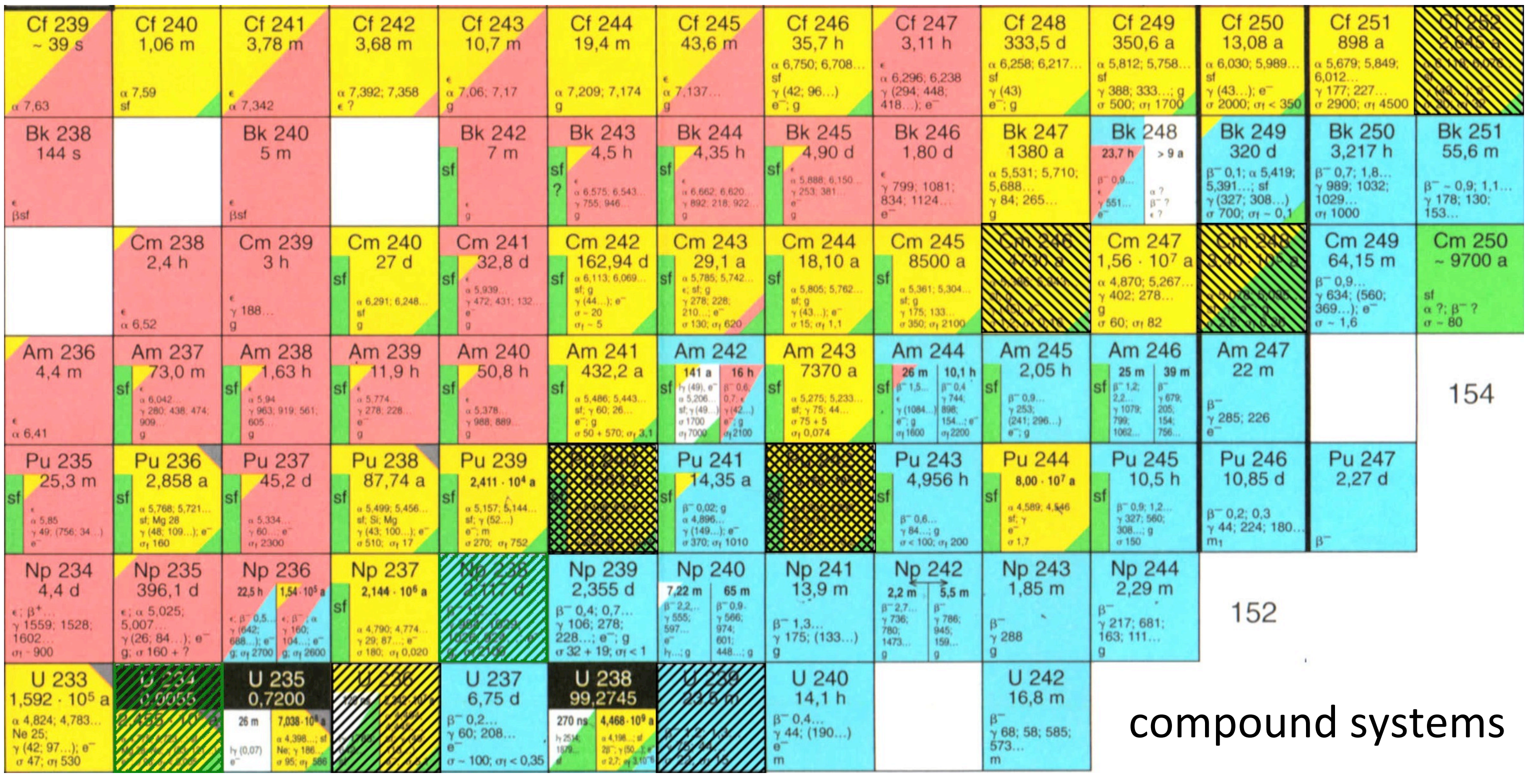
PFGS characteristics as function of A, Z and E_x



(n, f) ▨ previous work

▨ upcoming work

(sf) ▧ previous work

Introduction
The Co-workers

Introduction
The Co-workers

Quote: “It started as a family business... now it's a "gang" ;-)”

Patrick Talou, July 6, 2017

Introduction

"The Gang"

T. Belgya, R. Billnert, R. Borcea, T. Brys, A. Chatillon, D. Choudhury, S. Courtin, M. Fallot, G. Fruet, A. Gatera, W. Geerts, G. Georgiev, A. Göök, C. Guerrero, P. Halipré, F.-J. Hambsch, D.G. Jenkins, Z. Kis, B. Laurent, M. Lebois, L. Le Meur, A. Maj, P. Marini, B. Maróti, T. Martinez, I. Matea, A. Moens, L. Morris, V. Nanal, P. Napiorkowski, A. Porta, F. Postelt, A. Oberstedt, S. Oberstedt, L. Qi, L. Szentmiklosi, K. Takàcs, S. J. Rose, G. Sibbens, S. Siem, C. Schmitt, O. Serot, M. Stanoiu, D. Vanleeuw, M. Vidali, B. Wasilewska,J.N. Wilson, A.-A. Zakari, F. Zeiser …

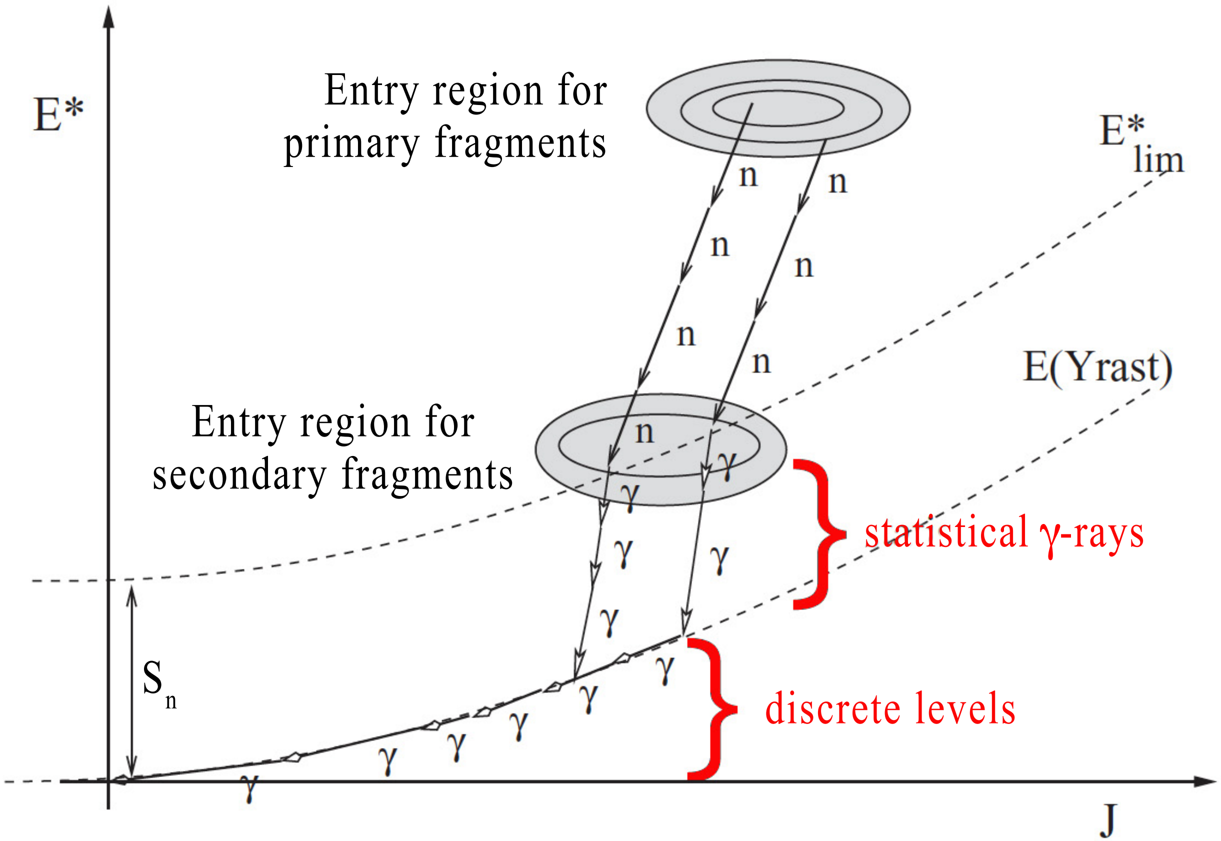
PhD students

Introduction

- For many years: precise measurement of prompt fission γ-ray spectra (PFGS)
- Determination of characteristics:
  - $< M_\gamma >$, $< \varepsilon_\gamma >$, and $< E_{\gamma,tot} >$
- Studies of the dependence of A, Z, and E_x
- Now: focus on the de-excitation process of fission fragments

Introduction

Sequential emission of neutrons and γ-rays



According to: Litaize & Serot, PRC 82, 054616 (2010)

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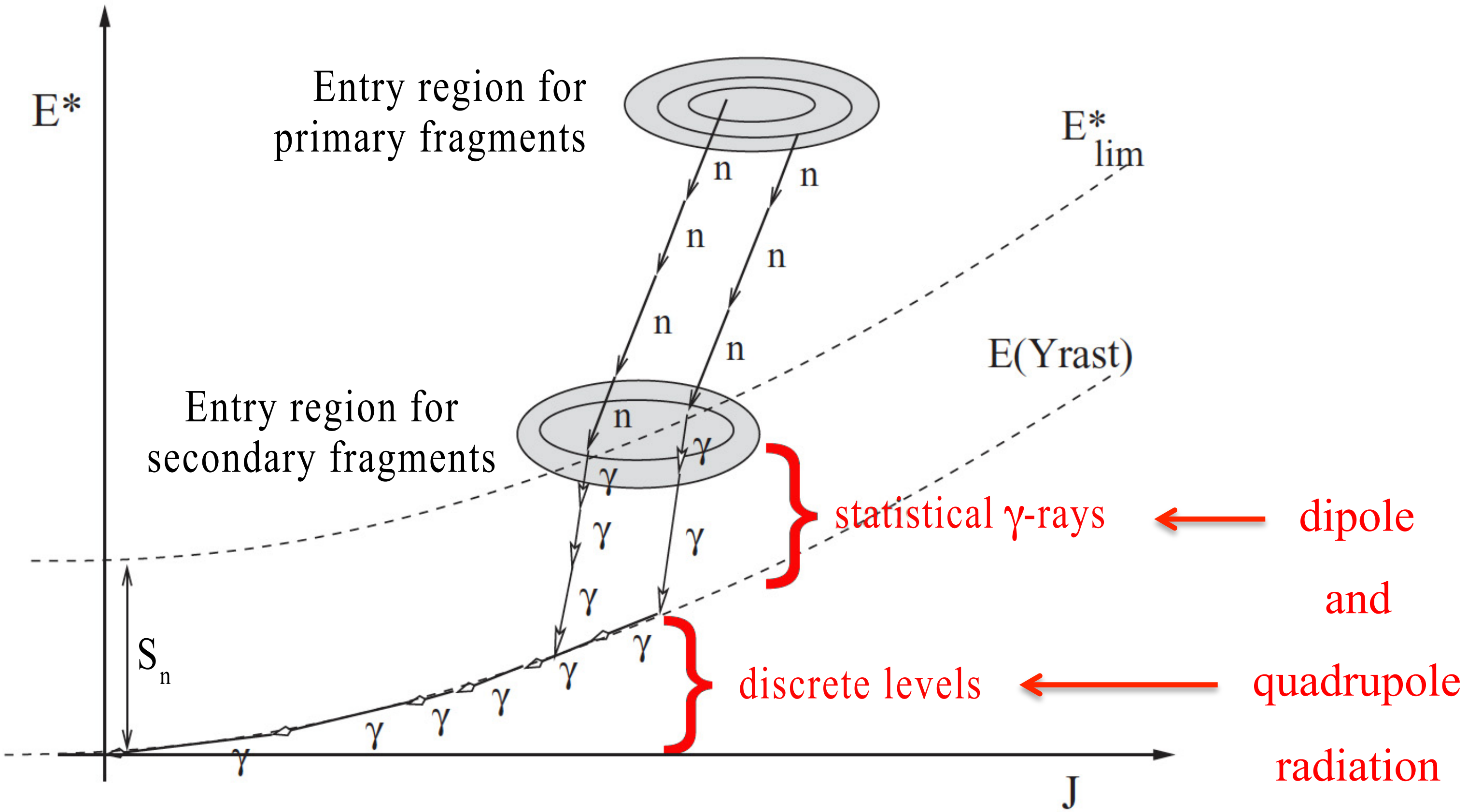
Sequential emission of neutrons and γ-rays



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Introduction

- For many years: precise measurement of prompt fission γ-ray spectra (PFGS)
- Determination of characteristics:
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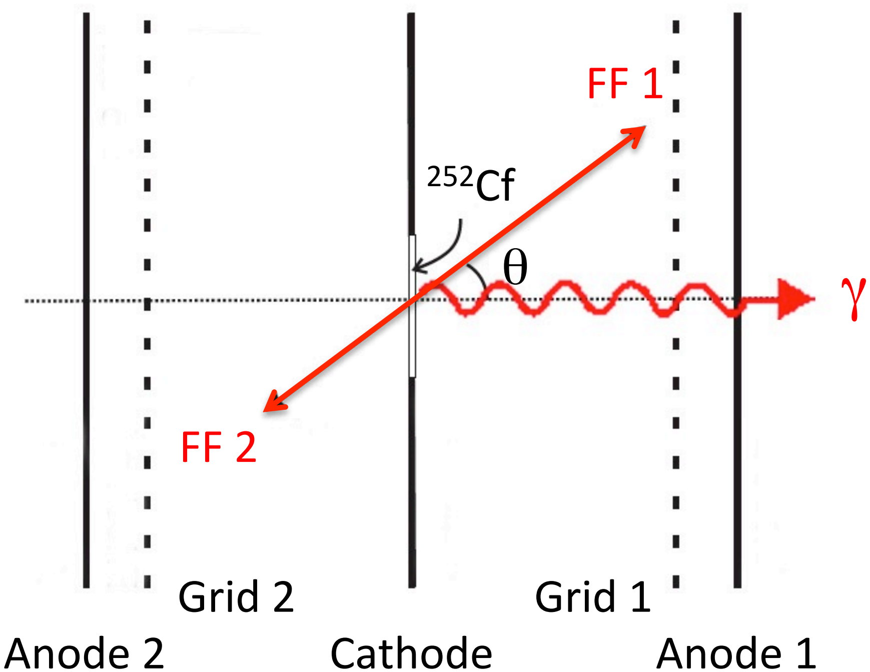
- Studies of dependence of A, Z, and E_x
- Now: focus on the de-excitation process of fission fragments
- Measurement of PFG angular distributions !

Experimental setup

Frisch grid ionization chamber + $LaBr_3$ detector



3 in. × 3 in.

Correlations between fission fragments and γ-rays

Data treatment

Detector response matrix vs. transformation matrix

measured spectrum — response matrix — emission spectrum

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ \\ y_n \end{pmatrix} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & & & \\ \vdots & & & \vdots \\ & & & \\ r_{n1} & & \cdots & r_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ \\ x_n \end{pmatrix}$$

Data treatment

Detector response matrix vs. transformation matrix

$$\underbrace{\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ \\ y_n \end{pmatrix}}_{\text{measured spectrum}} = \underbrace{\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & & & \\ \vdots & & & \vdots \\ & & & \\ r_{n1} & & \cdots & r_{nn} \end{pmatrix}}_{\text{response matrix}} \underbrace{\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ \\ x_n \end{pmatrix}}_{\text{emission spectrum}}$$

usually simulated (*GEANT4*, *PENELOPE*)

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diagonalized

$$= \begin{pmatrix} r'_{11} & 0 & \cdots & & 0 \\ 0 & r'_{22} & & & \\ \vdots & & \ddots & & \vdots \\ & & & & 0 \\ 0 & & \cdots & 0 & r'_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ \\ x_n \end{pmatrix}$$

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Detector response matrix vs. transformation matrix

measured spectrum | response matrix | emission spectrum

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if both are known ...

diagonalized

$$= \begin{pmatrix} r'_{11} & 0 & \cdots & & 0 \\ 0 & r'_{22} & & & \\ \vdots & & \ddots & & \vdots \\ & & & & 0 \\ 0 & & \cdots & 0 & r'_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ \\ x_n \end{pmatrix}$$

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$$

… this matrix can be determined, e.g. by $r'_{ii} = y_i / x_i$!

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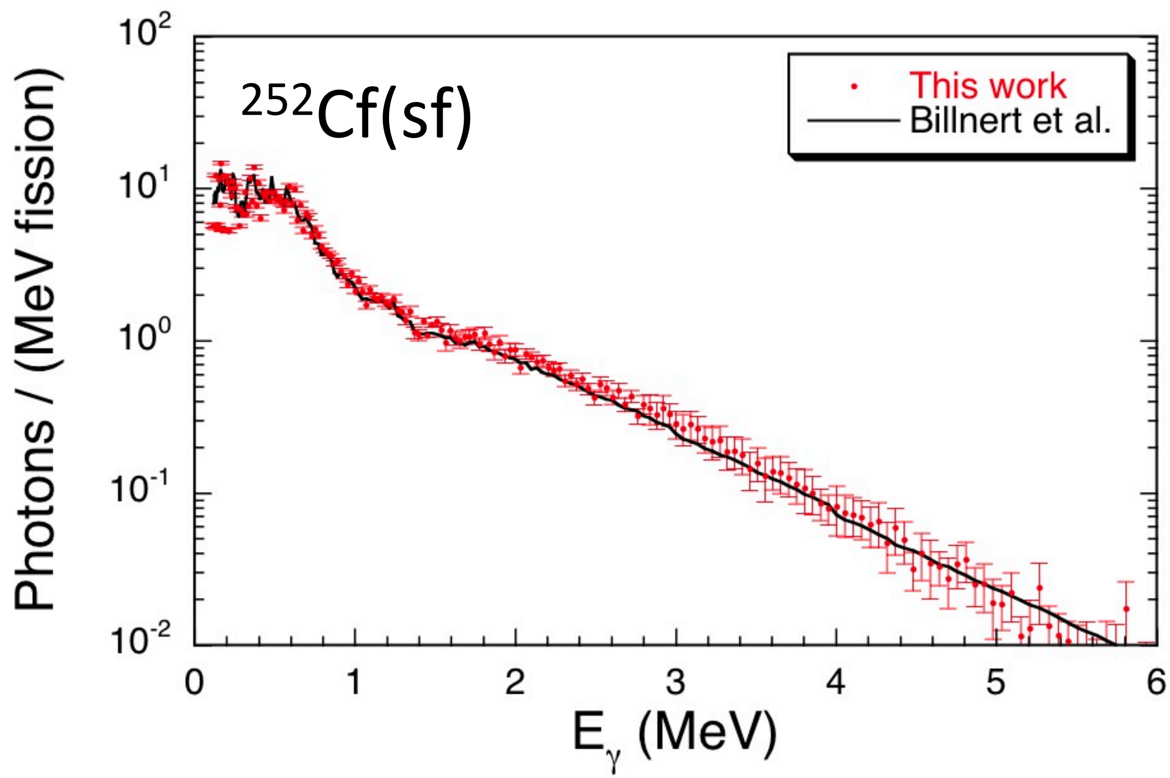
... this matrix can be determined, e.g. by $r'_{ii} = y_i / x_i$!

Applied to other measurements (same conditions)!

Preliminary results

Prompt fission γ-ray spectra (PFGS)



Good agreement between this work and a previously measured spectrum

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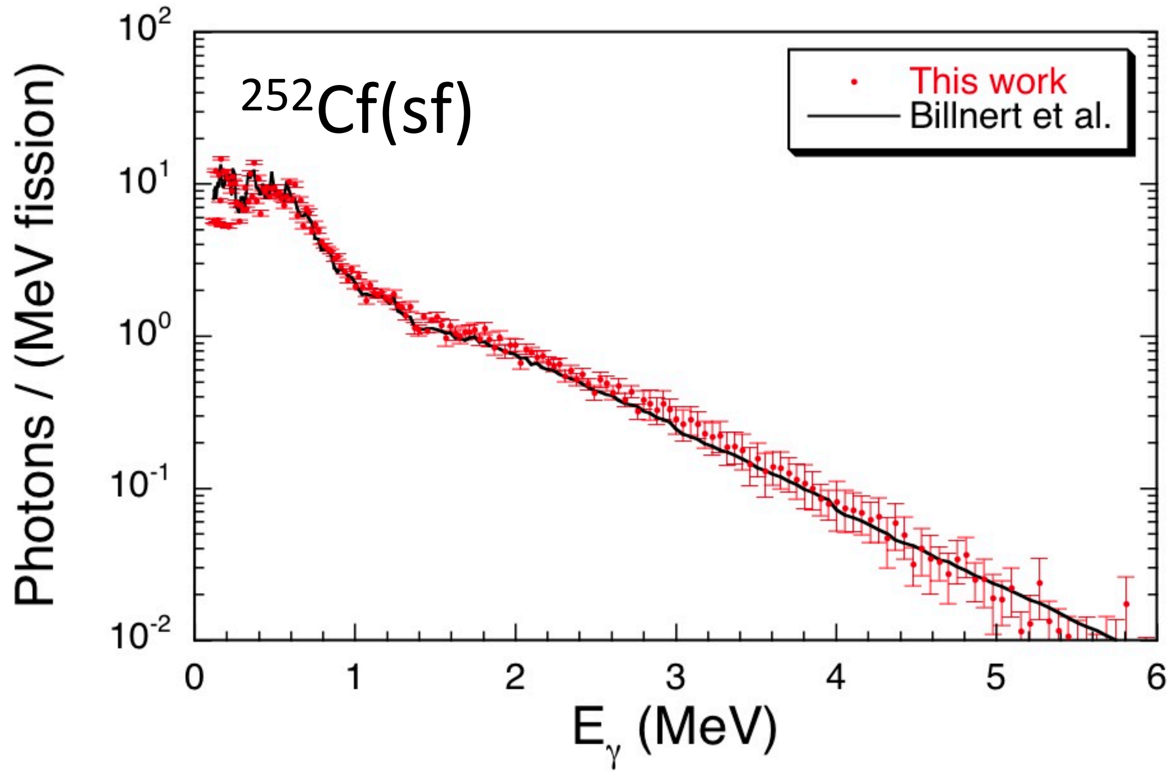
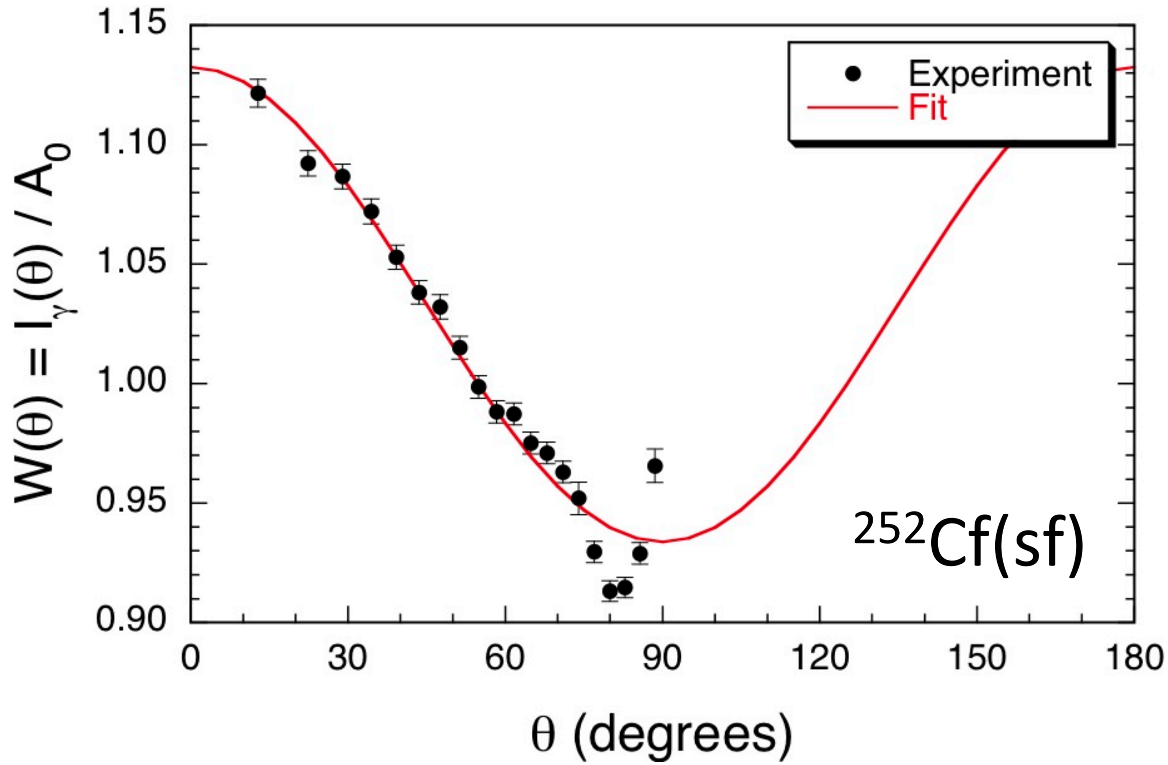


Good agreement between this work and a previously measured spectrum → repeat for different cosθ bins !

Preliminary results
Angular distribution

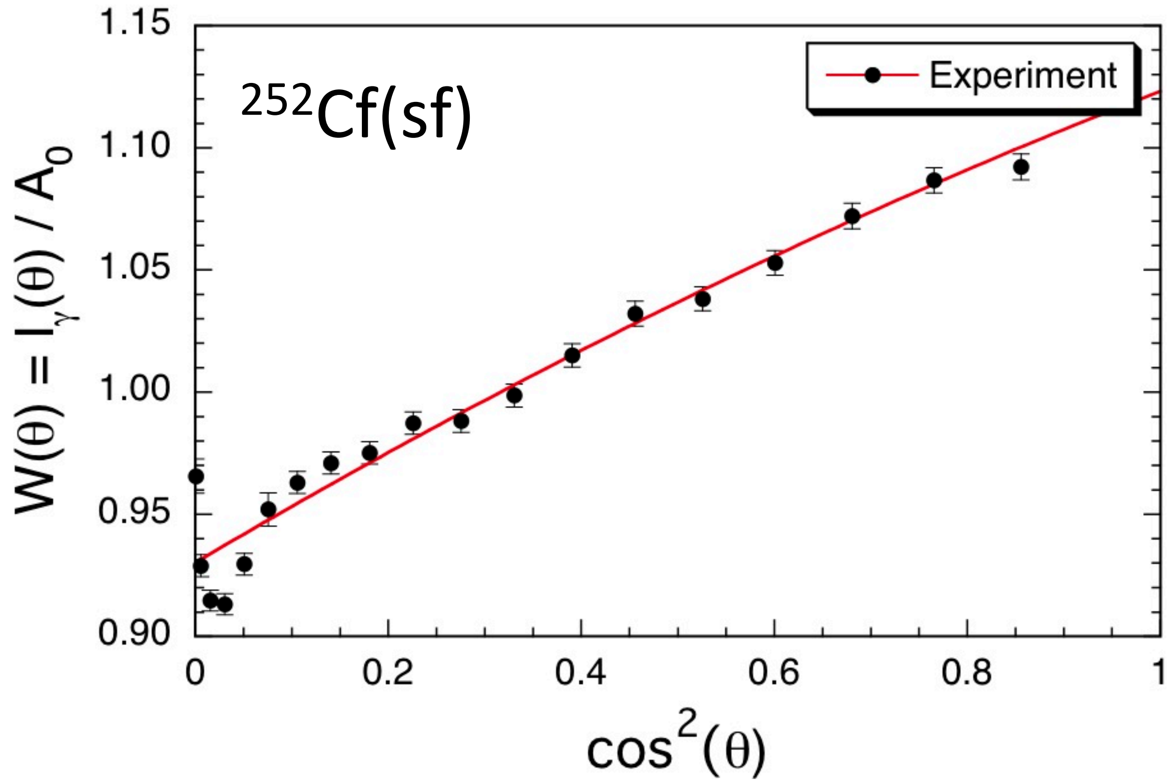


Statistical uncertainties only!

$$\text{Fit: } W(\theta) = A_0\,[1 + \{A_2/A_0\}P_2(\cos\theta) + \{A_4/A_0\}P_4(\cos\theta)]$$

Preliminary results

Angular distribution

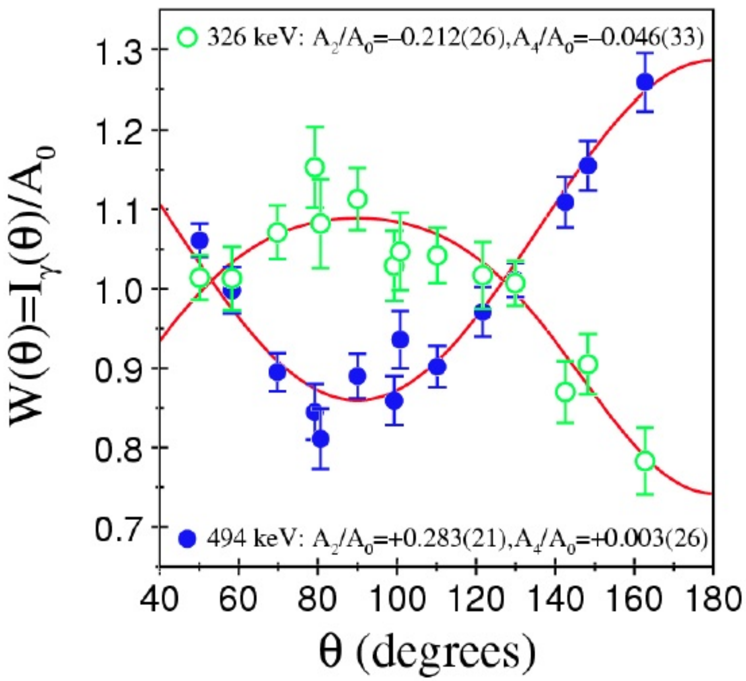


Statistical uncertainties only!

Fit result: $\{A_2/A_0\} = 0.13 \pm 0.03$

Preliminary results
Angular distribution

Angular Distributions in ^{109}Te

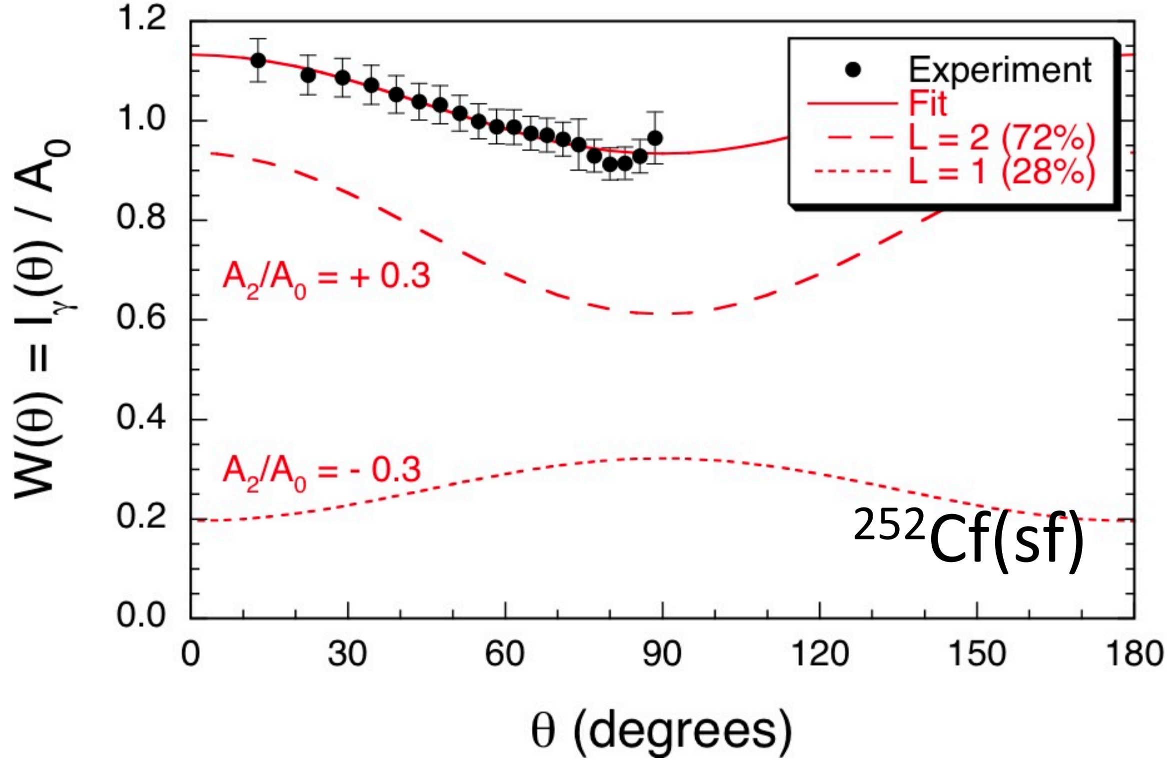


- Typically A_4/A_0 is close to zero
- And A_2/A_0 ~ +0.3 for a pure quadrupole (ΔI = 2) transition
- Or A_2/A_0 ~ -0.3 for a pure dipole (ΔI = 1) transition

30/08/2013 Postgraduate Summer School, Bristol : E.S. Paul 13

Preliminary results

Angular distribution



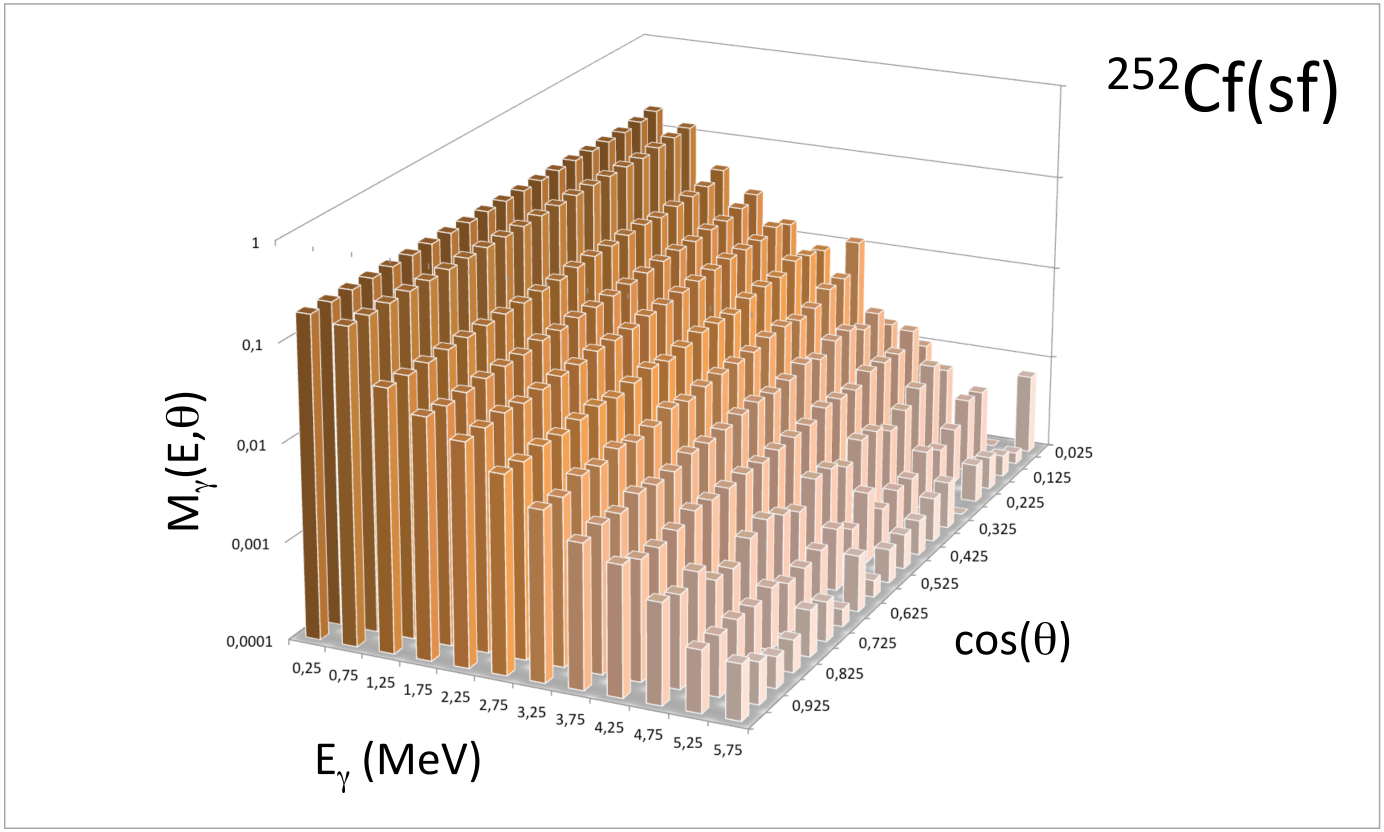
Statistical + systematic uncertainties!

Theory: $\{A_2/A_0\} = +\ 0.3$ for quadrupole radiation

$\{A_2/A_0\} = -\ 0.3$ for dipole radiation

Preliminary results

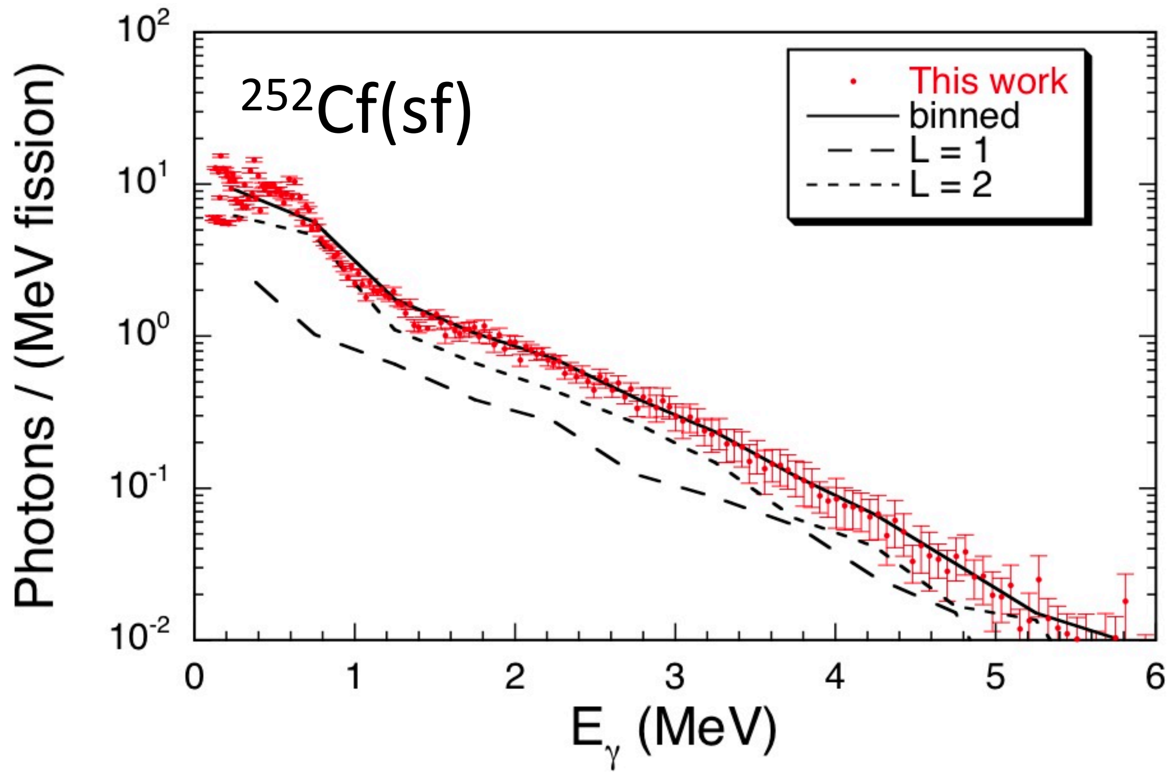
Angular distributions for 500 keV energy bins



→ again: fit of Legendre polynomials

→ decomposition of multipolarities L = 1and 2

Preliminary results
Multipolarity-dependent PFGS

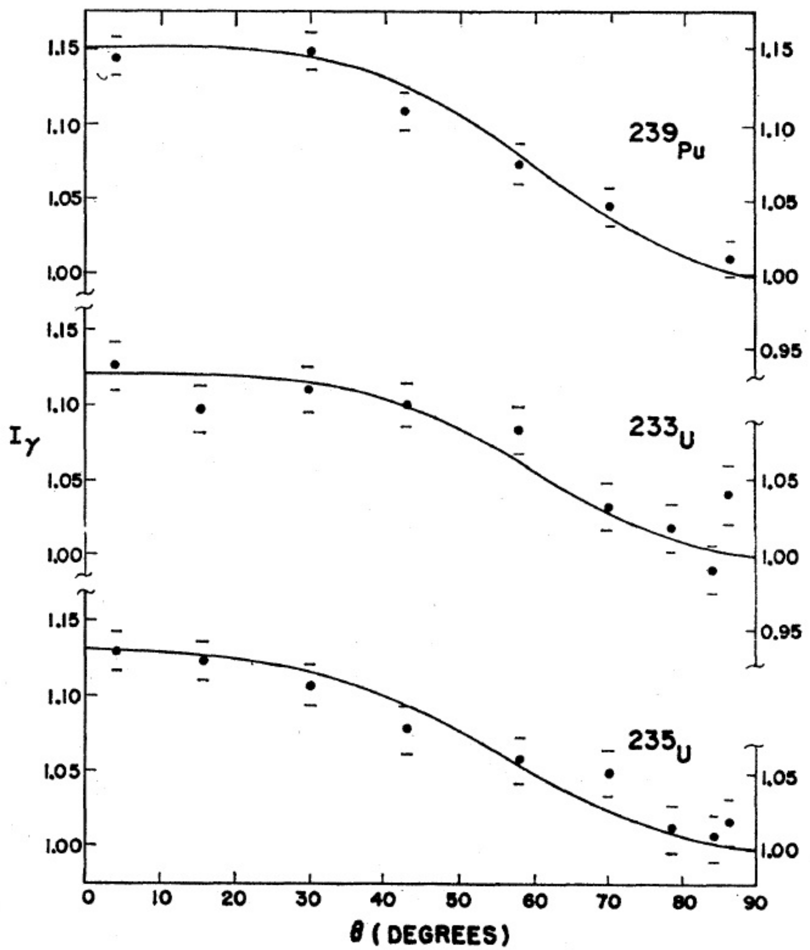


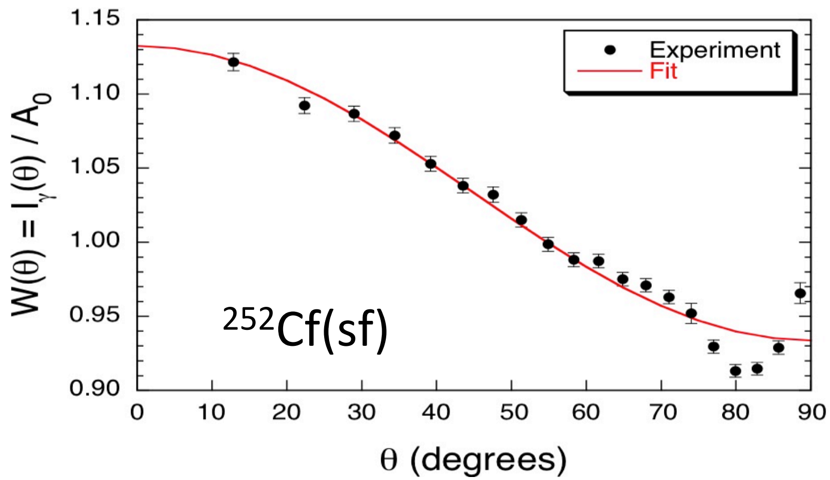
→ multipolarity-dependent spectra

→ multipolarity-dependent PFGS characteristics

Discussion

Previously measured angular distributions *)

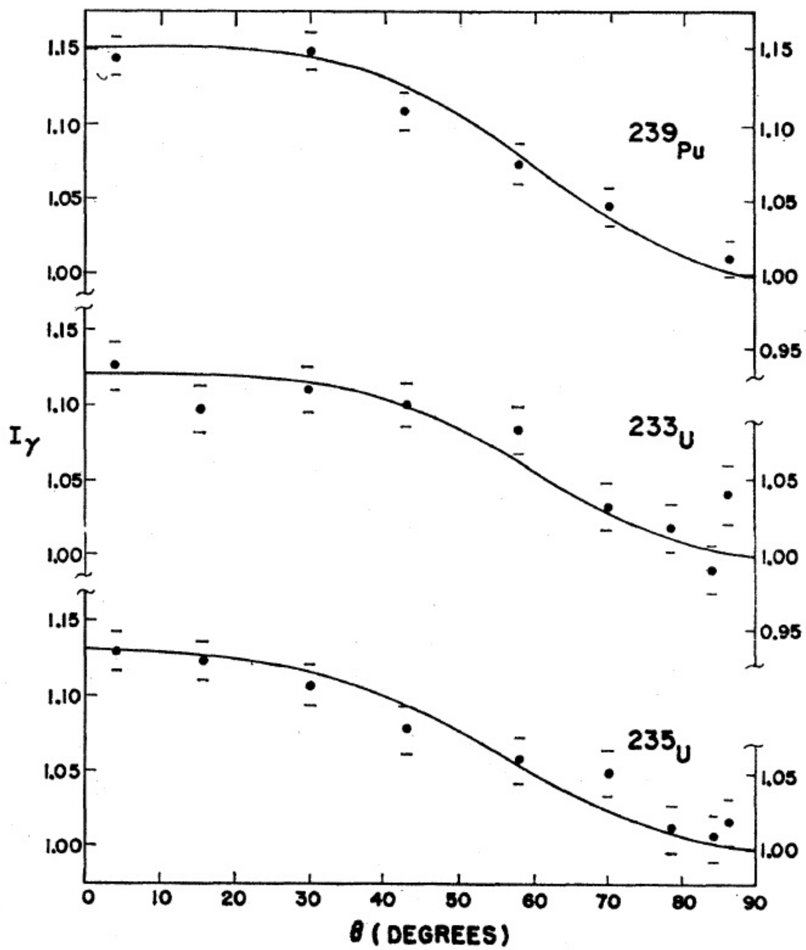


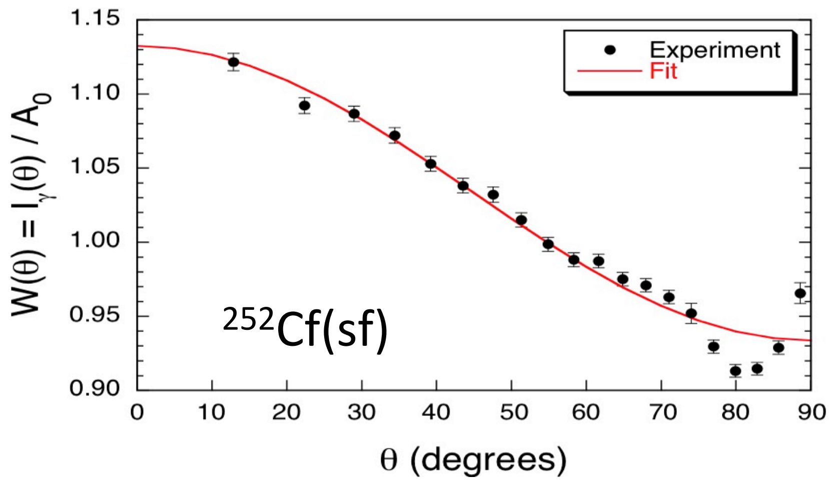


*) Hoffman, Phys. Rev. 133 (1964)

Discussion

Previously measured angular distributions *)



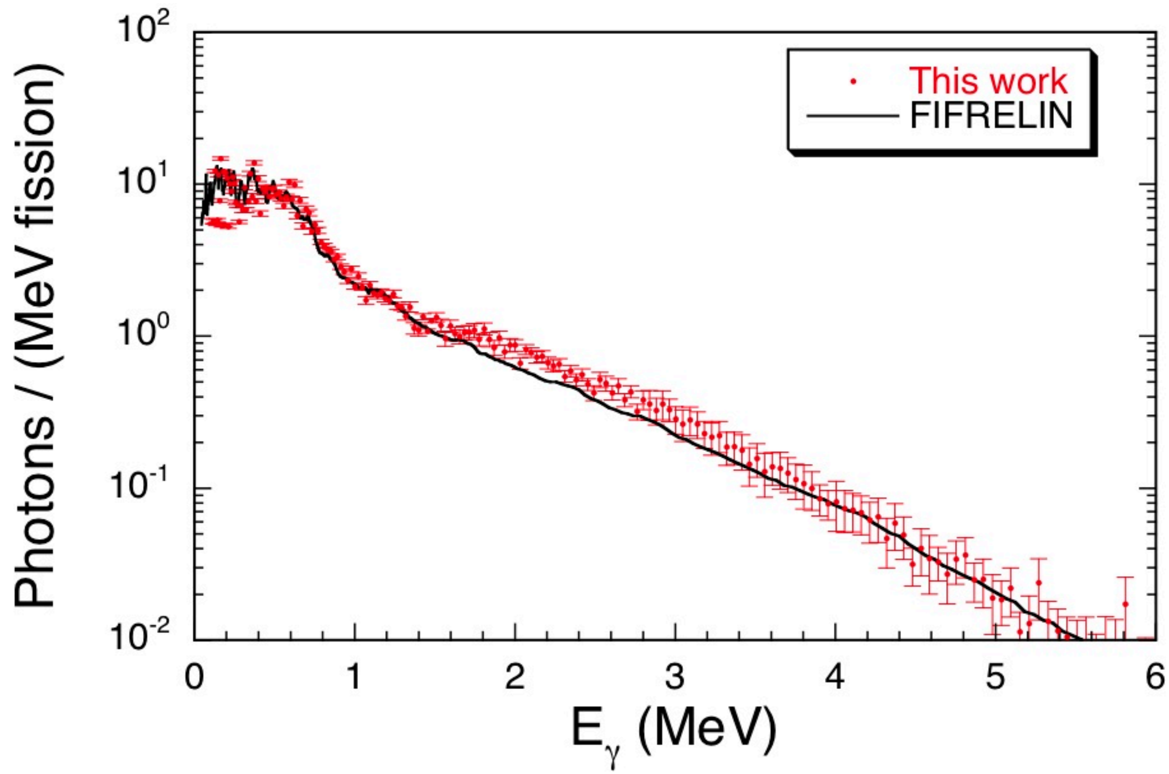


Good agreement in dominating E2 character !

*) Hoffman, Phys. Rev. 133 (1964)

Discussion

Comparison with FIFRELIN calculations *)



*) A. Chebboubi, priv. comm.

Good agreement between integral spectra!

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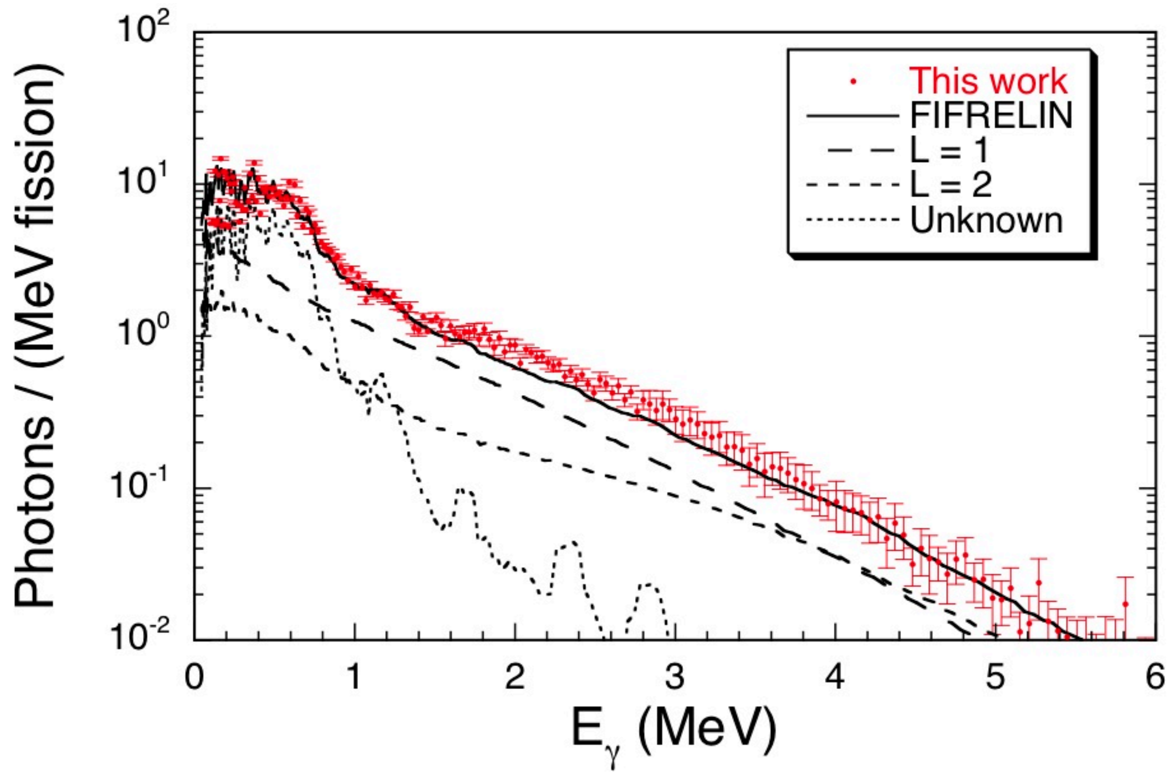
Comparison with FIFRELIN calculations *)



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Good agreement between integral spectra!

But FIFRELIN also provides multipolarity-dependent PFGS.

Discussion

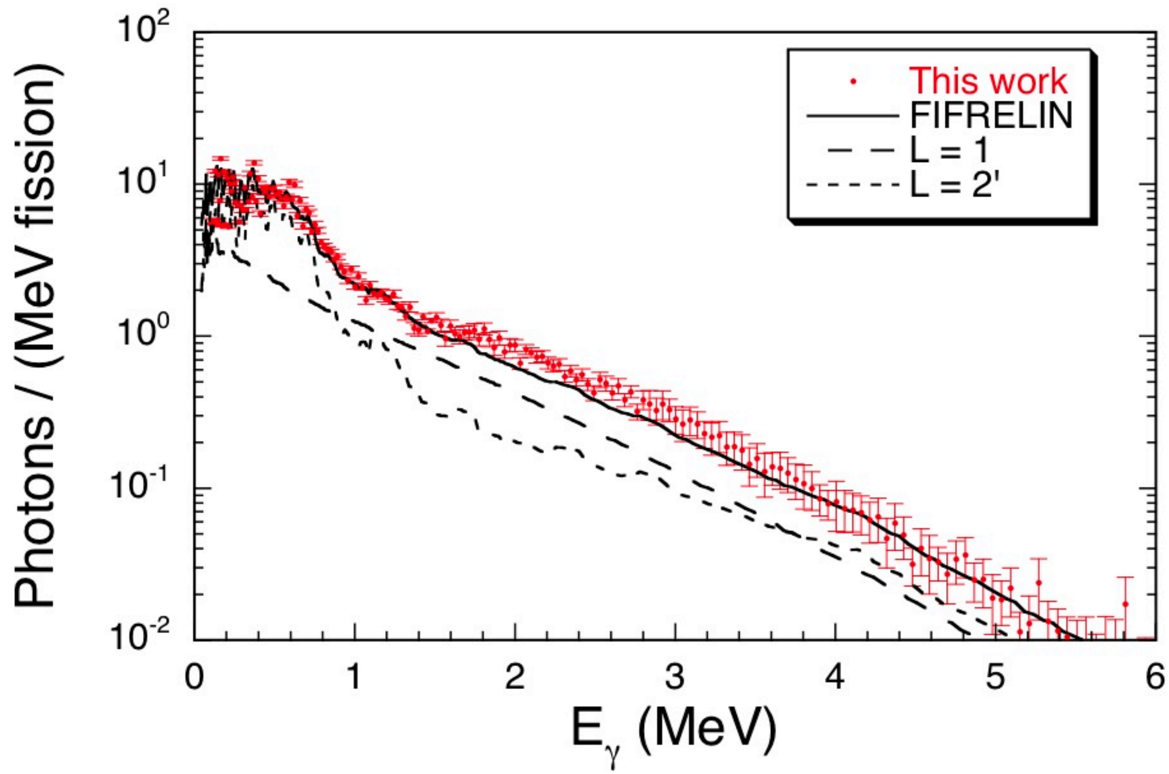
Comparison with FIFRELIN calculations *)

	Experiment (this work)		Calculations (FIFRELIN)	
$\bar{M}_\gamma$	8.28 ± 0.51		8.28	(adjusted)
$\bar{M}_\gamma$ (L = 1)	2.31	(28 %)	3.20	(39 %)
$\bar{M}_\gamma$ (L = 2)	5.97	(72 %)	1.45	(17 %)
$\bar{M}_\gamma$ (unknown)	---		3.63	(44 %)
$\bar{\varepsilon}_\gamma$	0.79 ± 0.10	(MeV)	0.76	(MeV)
$\bar{\varepsilon}_\gamma$ (L = 1)	0.86	(MeV)	0.94	(MeV)
$\bar{\varepsilon}_\gamma$ (L = 2)	0.76	(MeV)	1.03	(MeV)
$\bar{\varepsilon}_\gamma$ (unknown)	---		0.50	(MeV)
$\bar{E}_\gamma$	6.51 ± 0.76	(MeV)	6.30	(MeV)
$\bar{E}_\gamma$ (L = 1)	1.99	(MeV)	3.00	(MeV)
$\bar{E}_\gamma$ (L = 2)	4.52	(MeV)	1.49	(MeV)
$\bar{E}_\gamma$ (unknown)	---		1.81	(MeV)

*) A. Chebboubi, priv. comm.

Discussion

Comparison with FIFRELIN calculations *)



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From our observations: unknown transitions → L = 2,
L = 2 + unknown → L = 2'.

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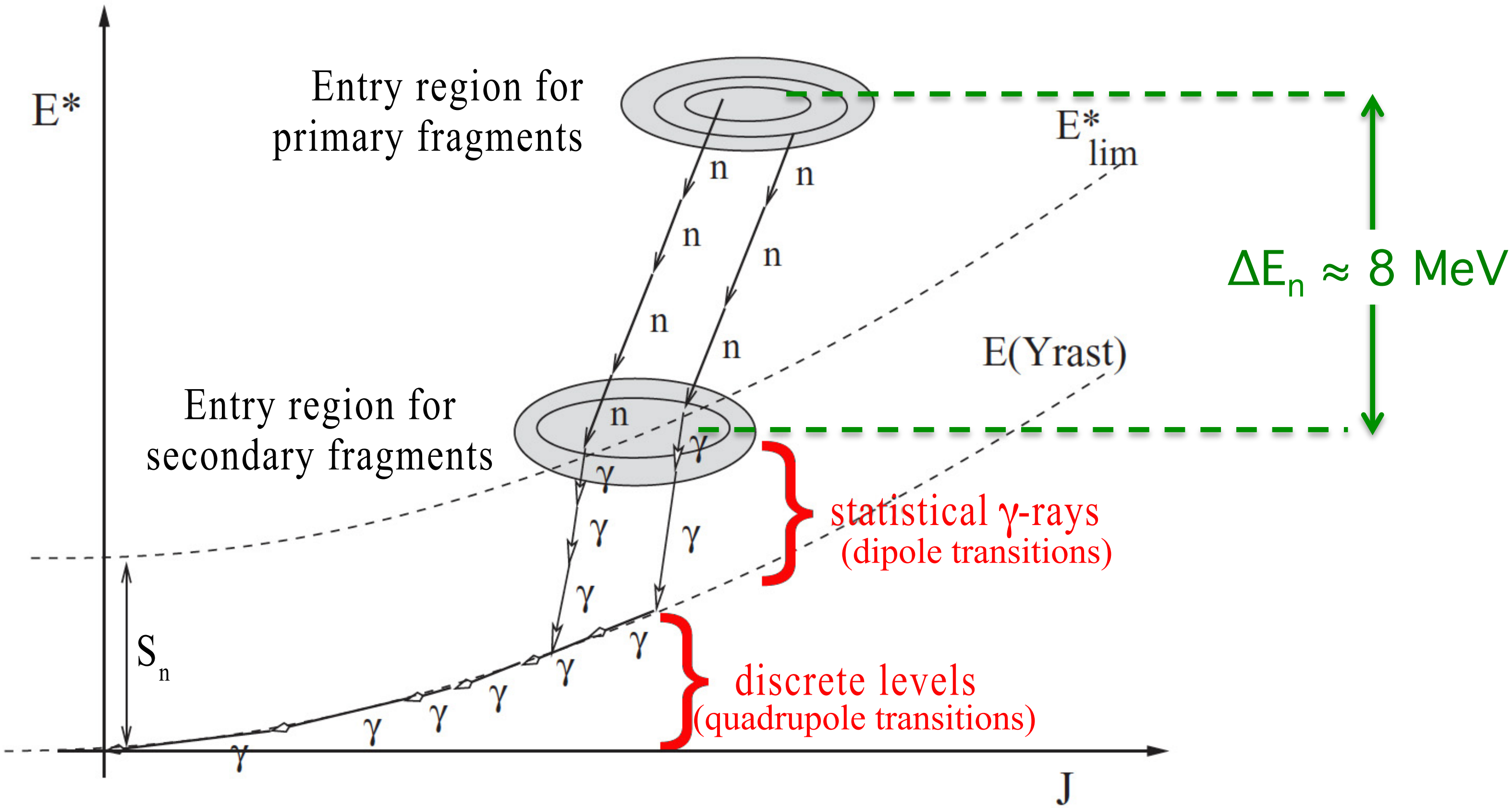
Summary

- Measured angular distribution of prompt γ rays from $^{252}Cf(sf)$ → dominant E2 character, in good agreement with previous measurements
- With $< M_{\gamma} > \approx 8.3$ follows
  - $<M_{\gamma,L=1}> \approx 2.3$ and $<M_{\gamma,L=2}> \approx 6.0$

Summary

Sequential emission of neutrons and γ-rays



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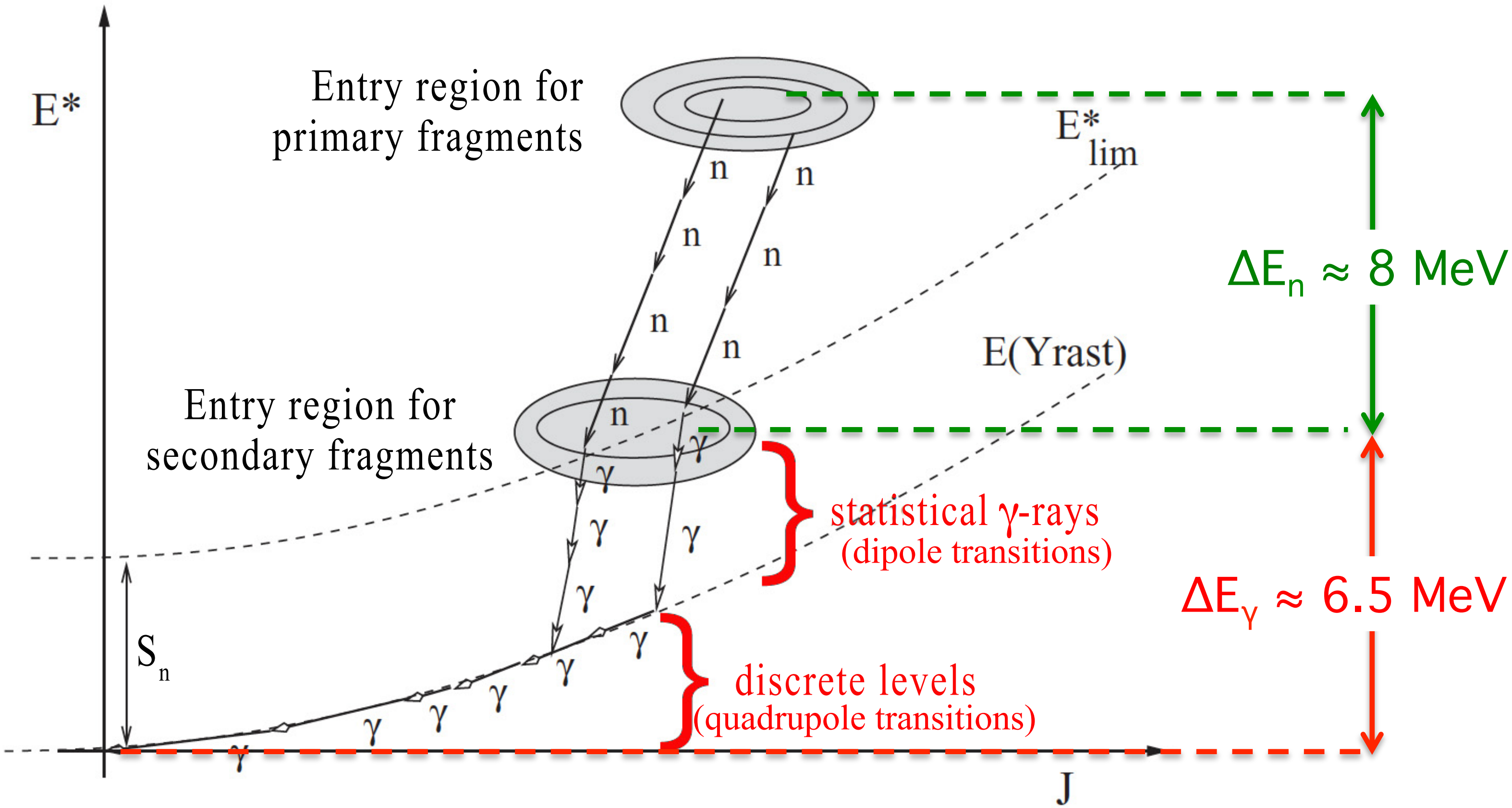
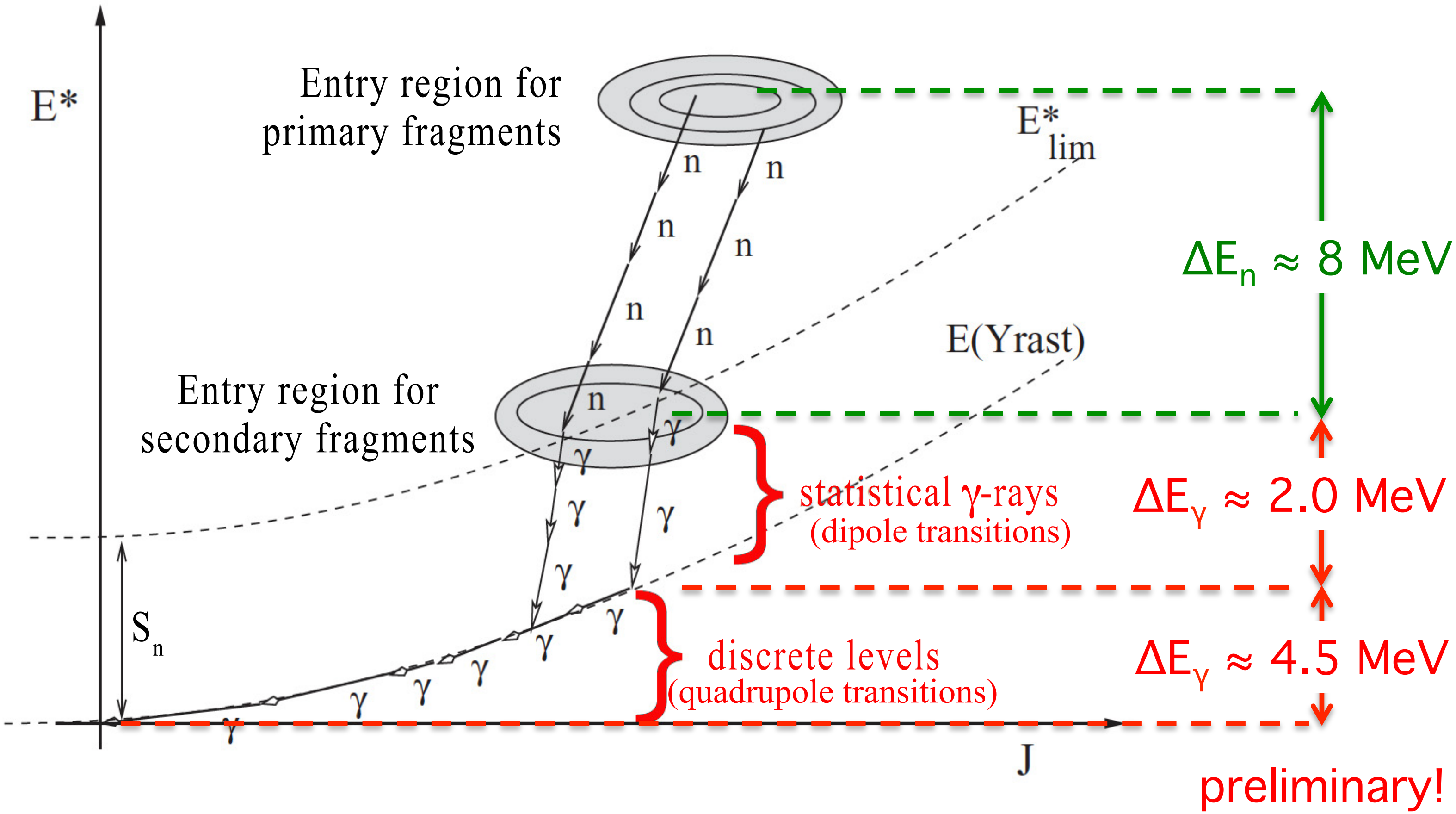


E*
Entry region for
primary fragments
n
n
n
n
n
n
n
E*lim
ΔEn ≈ 8 MeV
E(Yrast)
Entry region for
secondary fragments
γ
statistical γ-rays
(dipole transitions)
ΔEγ ≈ 6.5 MeV
Sn
discrete levels
(quadrupole transitions)
J

Summary



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Entry region for primary fragments
E*lim
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n
n
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n
n
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E(Yrast)
Entry region for secondary fragments
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statistical γ-rays
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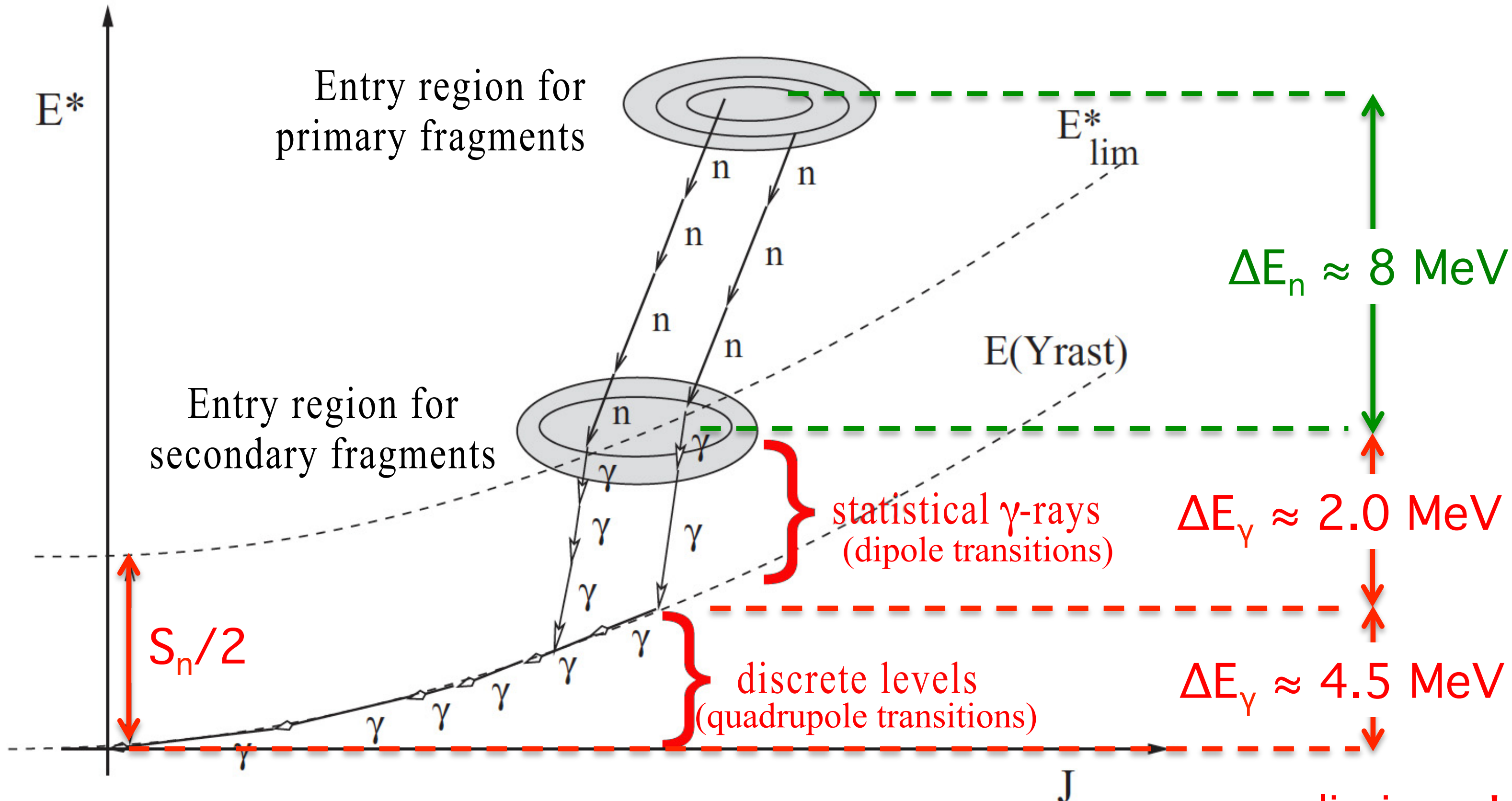
J
preliminary!

Summary



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- Average spin of fission fragments is $J \approx 12\ \hbar$, which seems a bit high, but still reasonable

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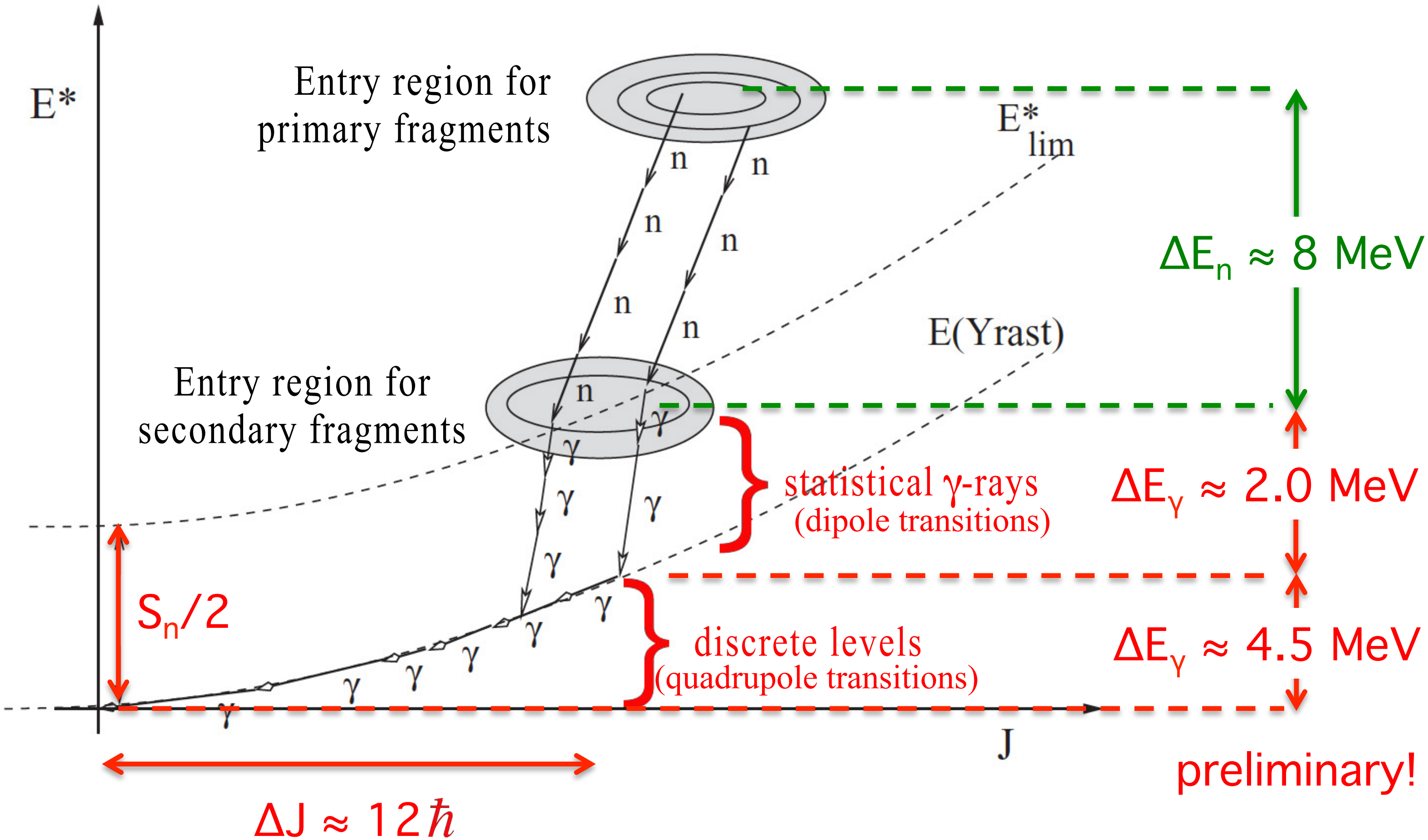

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- Average spin of fission fragments is $J \approx 12\ \hbar$, which seems a bit high, but still reasonable
- Comparison with FIFRELIN calculations shows rather good agreement …

Outlook

- ... that is even better with a more realistic (?) assumption $\{A_2/A_0\} \approx -0.2$ for dipole radiation,
- leading to
  - $<M_{\gamma,L=1}> \approx 2.8$ (34 %) and
  - $<M_{\gamma,L=2}> \approx 5.5$ (66 %)
- These results have to be compared with other related information on fission fragments, such as
  - average neutron separation energies
  - average moments of inertia etc.

The collaborators

A. Oberstedt, R. Billnert, A. Gatera, A. Göök, S. Oberstedt

Thank you!